



Evert Seevinck (M'75) was born in Doetinchem, The Netherlands, on April 15, 1945. He received the B.Sc. degree in mathematics and physics in 1966, the B.Sc. degree in electrical engineering in 1970, the B.Sc. Hons. degree in electronic engineering (cum laude) in 1975, and the D.Sc. degree in electronic engineering in 1981, all from the University of Pretoria, Pretoria, South Africa. His dissertation dealt with the analysis and synthesis of translinear integrated circuits.

From 1970 to 1972 he was with Philips Gloeilampenfabrieken in Nijmegen and Eindhoven, The Netherlands, where he worked on the design and application of analog integrated circuits. In 1973 he returned to South Africa where he joined Philips in Johannesburg, continuing IC application work. From 1975 to 1981 he was employed as Research Engineer at the Council for Scientific and Industrial Research (CSIR) in Pretoria where he performed research and development on novel circuit techniques and custom IC's. In 1981 he returned to Philips in The Netherlands, where he worked on analog IC design. In August 1983 he assumed his present post as Professor of Electrical Engineering at Twente University of Technology, Enschede, The Netherlands, where he teaches and performs research on the theory and design of electronic circuits. He maintains a consulting relationship with Philips,

Nijmegen, The Netherlands. He has published on analog and digital circuit techniques, systematic synthesis of translinear circuits, theoretical aspects of multilevel logic, nonlinear function approximation, and nonlinear circuit stability. He has several patents pending in the area of circuit design.



Jan de Groot was born in Poortugaal, The Netherlands, on April 29, 1937. He received the M.S. degree in electrical engineering from Delft University of Technology, Delft, The Netherlands, in 1963.

In 1966 he joined Philips Research Laboratories, Eindhoven, The Netherlands, where he has been working in the area of applied mathematics with emphasis on numerical analysis. He presently supervises a group for applied mathematics and statistics.

Mr. de Groot is a member of the Dutch Mathematical Society.

Regular Correspondence

A High Performance 256K (512K) Static ROM

EDISON FONG, JIASHANN CHANG, AND WEN PERNG TAI

Abstract—A 256K ROM, fully expandable to 512K, has been fabricated. The ROM utilizes a 2.5 μm NMOS multiple threshold technology. It has a typical access time of 120 ns and uses push-pull circuitry to achieve an active current of 60 mA and a standby current of 1.0 mA. Total chip size is 39K mil² for the 256K version. A modified X cell has been chosen which requires 7.5 $\mu\text{m} \times 7.5 \mu\text{m}$. Current sensing was chosen to optimize access time.

INTRODUCTION

The performance of MOS ROM's has increased extensively in the past five years, from 16K densities ten years ago to a 4 Mbit version for character generation reported in 1980 [1]. Access times have ranges from 45 ns to several hundred nanoseconds, depending on the density and application. Although EPROM's and EEPROM's have made significant advancements in the past few years, ROM's will remain dominant where the requirements of high volume, high density, high reliability, and low cost are of primary concern. The ROM described in this paper is a general-purpose ROM, and thus compromises were made to optimize overall performance. The 256K (32K \times 8) ROM is fully expandable to 512K with minimum changes. It has a 60 mA typical active power with a 1.0 mA standby. The low standby power is attributed to the extensive use of push-pull circuitry and a novel back bias generator. Because of its low standby power, it is feasible for battery-operated equipment. The ROM is fully static and is programmed via an ion implantation which increases

the threshold voltage of selected cells in the memory array. This technique is more economical than the traditional diffusion technique which must occur early in the processing sequence and thus extend lead time.

The architecture of the chip is shown in Fig. 1, with the die photo of the 256K version shown in Fig. 2(a). It is organized in eight 512 \times 64 groups for the 256K version and eight 1024 \times 64 groups for the 512K version. Through the use of predecoding, there are 128 NOR X-decoders (256 for the 512K), one for every four rows of cells. The cell chosen is a modified X cell [2] configuration requiring only 7.5 $\mu\text{m} \times 7.5 \mu\text{m}$. To optimize access time, current sensing was incorporated as described by Wong *et al.* [3].

PROCESS TECHNOLOGY

The ROM is fabricated on a basic 2.5 μm gate length, 500 Å NMOS polysilicon technology. Although CMOS would require less power, it was considered too costly, and the loss in density would not meet the requirements mentioned previously. Five thresholds are available, which include a hard depletion (−2.5 V), a soft depletion (−0.7), a soft enhancement (0.0 V), a hard enhancement (0.7 V), and a high threshold (+7.0) for programming. A polysilicon-to-diffusion contact is also available.

ADDRESS BUFFER

The address buffers consist of three inverter stages driving a push-pull output stage. The requirements of low power, minimum propagation delay, and in specific cases, high V_{out} are important. Probably the most critical stage is the first inverter in that it must be TTL compatible, even with variations in supply and process. To ensure TTL compatibility, the device dimensions of the first stage were designed conservatively.

The difference in this buffer is in the output stage. To conserve active power, soft enhancement devices were used as the output pull-ups. Unfortunately, this limits the maximum output level. If only soft enhancements were used, the maximum voltage for a HIGH level would be $2V_{\text{TSE}}$

Manuscript received January 28, 1983; revised May 3, 1983.

E. Fong is with the University of Santa Clara, Santa Clara, CA 94053 and the Signetics Corporation, Sunnyvale, CA 94086.

J. Chang is with the Signetics Corporation, Sunnyvale, CA 94086.

W. P. Tai is with the University of California, Berkeley, CA 94720 and the Signetics Corporation, Sunnyvale, CA 94086.

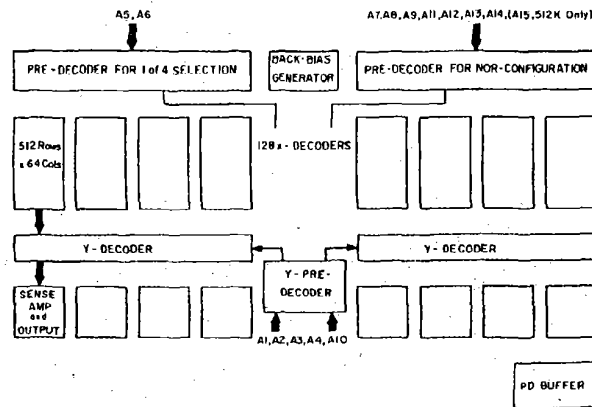


Fig. 1. Architecture of the 256K ROM. The 512K version uses 1024 rows.

(two soft enhancement thresholds) below V_{cc} . This is due to the output device and the power-down device of the previous stage. To minimize this limitation, small depletion devices were placed in parallel with the soft enhancement output devices. This increases the active power by a minimum amount, but allows the output to reach V_{cc} . In the power-down mode, current paths to ground are disabled. The output of both nodes of the address buffers go to approximately $V_{cc}/2$ in the power-down mode. This configuration allows for an improved chip enable time since the outputs of the buffer need only swing $V_{cc}/2$ when the chip is selected.

X DECODER

The design of X decoders is always difficult since compromises must be made. The X decoder in the 256K ROM desires the following three features. First, the overall power of all the decoders must be kept extremely low since there are 128 of them. Second, the circuitry must fit in the memory cell pitch, which eliminates complex schemes such as bootstrapping. Lines $WL1-WL4$, as shown in Fig. 3, expand the horizontal length of the X decoder which consumes significant silicon area. Third, the word line should have good voltage swings to provide good signal margins which lead to improve access times.

To alleviate the first problem, predecoding was used to drop the X decoder count to 128 rather than 512 in the 256K version. In addition, this allowed for a $30\text{ }\mu\text{m}$ pitch for each decoder. Poly-to-diffusion spacing was reduced to zero to fit the decoder in the prescribed pitch. This technique increased parasitic capacitance, but did not impair the functionality of the chip.

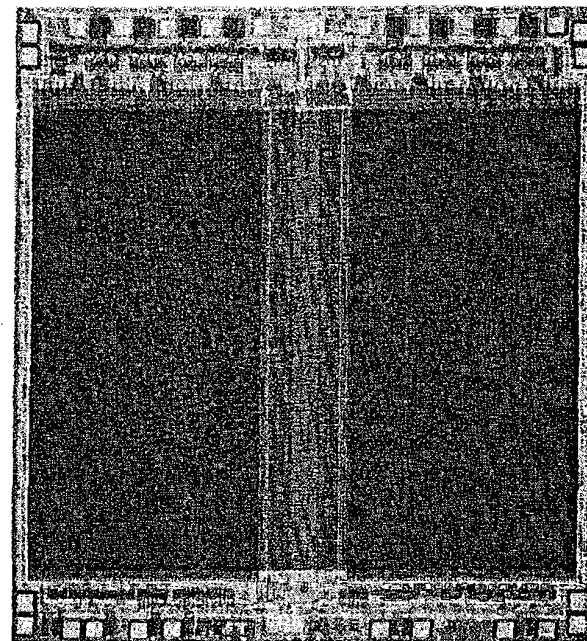
Lines $A01$, $A02$, $A03$, and $A04$ of Fig. 3 come from two addresses ($A5$ and $A6$), which determines a one of four selection from a predecoder in the periphery. This predecoder consists solely of push-pull circuitry with bootstrapping to preserve speed, output voltage swing, and power consumption.

The NOR gate devices of the X decoder come from predecoded lines utilizing addresses $A7$, $A8$, $A9$, $A11$, $A12$, $A13$, and $A14$. These decoders are push-pull, but contain no bootstrapping circuitry since the outputs feed into gates of inverters. Each pull-down device in the NOR configuration ($M1-M4$) has four predecoded metal lines associated with it, giving a total of 16 metal lines.

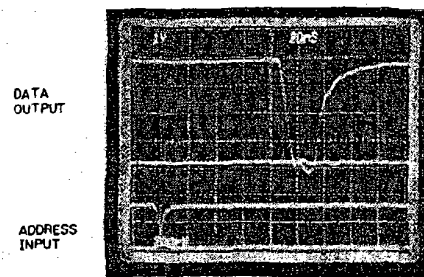
The majority of the active current is consumed in the X decoder. This is due to the NOR configuration. Push-pull circuitry could not be used due to the $30\text{ }\mu\text{m}$ pitch limitation. The maximum output of the word line is one V_{TSE} (one soft enhancement threshold) below V_{cc} . It is thus crucial for lines $A01-A04$ to reach V_{cc} to preserve speed.

Y DECODER

The Y decoder uses floating grounds to achieve a select. A schematic of one section of the decoder is shown in Fig. 4. For each bit, 16 sections of what is shown in Fig. 4 are used. When a memory cell ($M1$) is selected, one side of the cell is grounded through $M2$, while the other side



(a)



(b)

Fig. 2. (a) Die photograph of the ROM (256K). (b) Typical access photograph.

completes a path to the sense amplifier. The advantage of this technique is that the cell is kept very small, as shown in Fig. 5. The disadvantage of this technique is that the decoding is more complex. Y predecoders were designed using push-pull techniques, but bootstrapping was not used due to its increased silicon area.

CELL STRUCTURE

Fig. 5 shows the modified X cell configuration. This cell was chosen because of its compact size as compared to a conventional T cell approach which would have required $8\text{ }\mu\text{m} \times 8.5\text{ }\mu\text{m}$ with the same process design rules. The X cell minimizes area because the poly-to-contact spacing becomes the limiting design rule. The conventional T cell is contact-space-limited which requires, typically, 20 percent more area. The X cell has been modified slightly by clipping the edges of the metal-to-diffusion contact, which results in a 20 percent savings in area as compared to the conventional X cell previously reported [2]. The effective transistor size is approximately $3.5/2.5\text{ }\mu\text{m}$.

In designing with the X cell, other problems arise, primarily parasitic currents which decrease signal margins. Fig. 4 illustrates such an example. Suppose that $M1$ of Fig. 4 is selected. This requires the first bit line to go low. Simultaneously, $M2$ and $M3$ must be "on," which is determined by the Y predecoder. If $M1$ has a transistor, then bit line 2 is low. However, sharing this node is $M4$. If, again, there is a transistor present at $M4$, it will pull up bit line 2. This parasitic path decreases signal margins on an

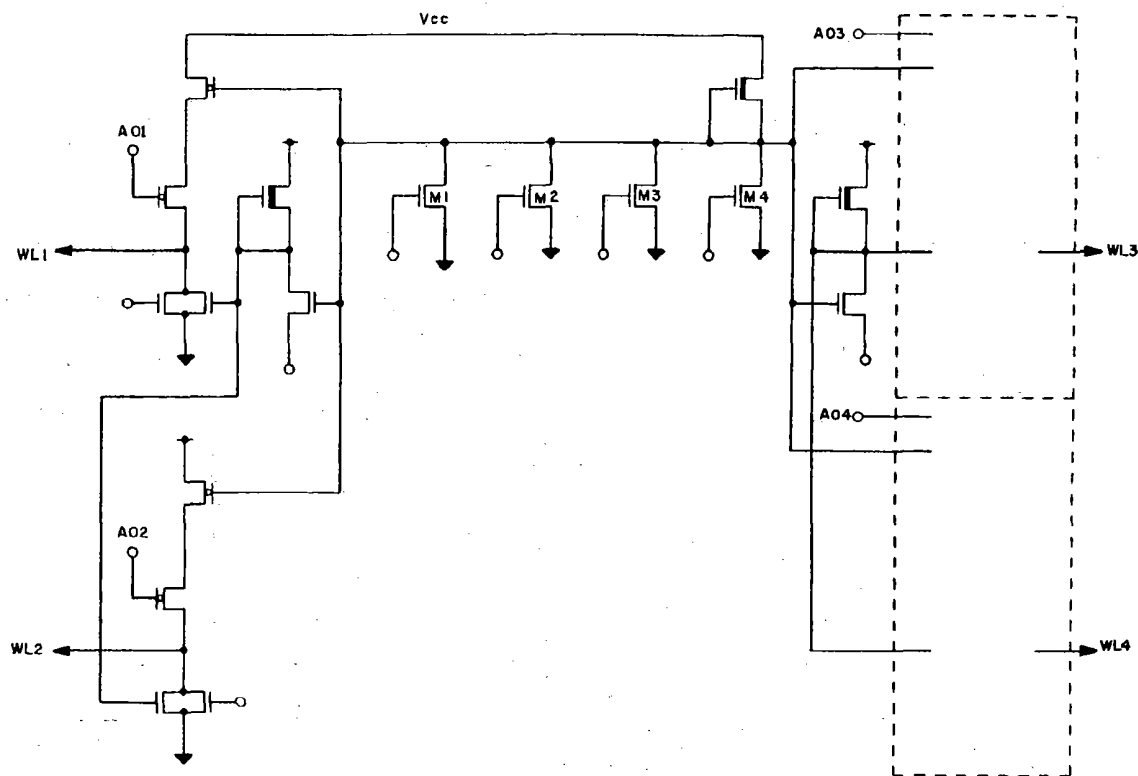


Fig. 3. Schematic diagram of the X decoder.

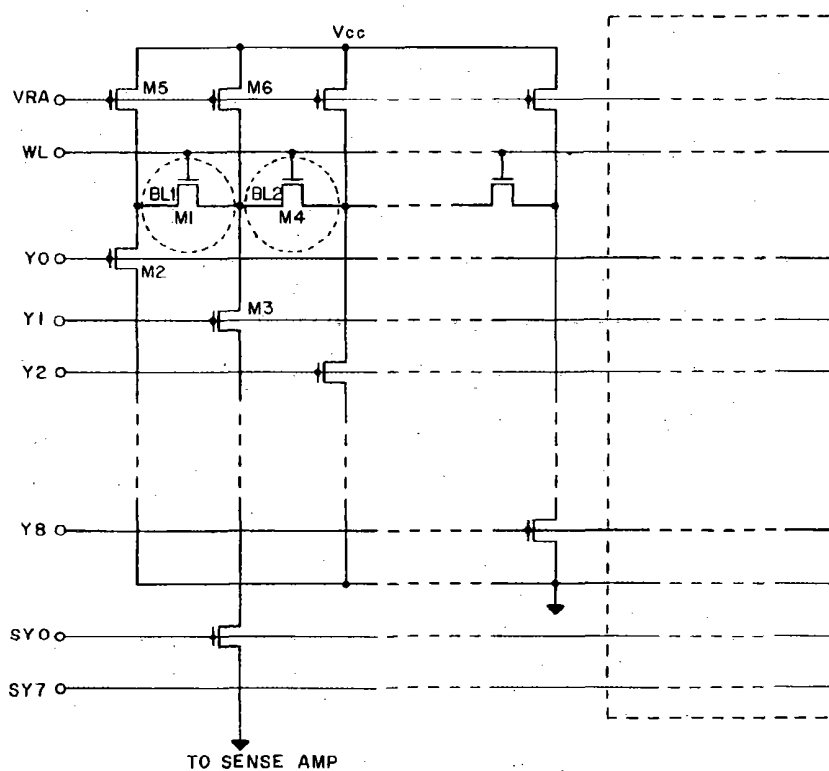


Fig. 4. Y decode path.

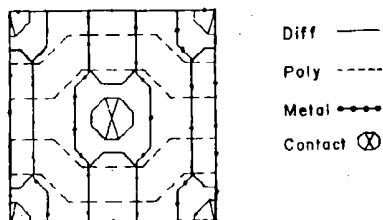


Fig. 5 The modified X-cell with clipped edges requiring $7.5\ \mu\text{m} \times 7.5\ \mu\text{m}$

already small cell (3.5/2.5). One technique to minimize this problem is to have the bit line pull-ups at the sense amplifier. In the present design, $M6$ will precharge bit line 2, but the sense amp will pull bit line 2 higher than that available from $M6$. Thus, minimum current will flow through $M4$. Voltage V_{RA} is designed so that the voltage which appears at the bit line is slightly lower than that of the sense amplifier. When the sense amplifier is activated, most of the current flows through the sense amplifier. This technique improves access time because the bit line is already charged prior to a select. However, this scheme reduces the signal current into the sense amp since the current path to ground for $M6$ is the memory cell. To minimize the current in $M6$ when a cell is selected, it is crucial for V_{RA} to be set low so that the bit line is below the inherent voltage of the sense amp. In the design presented in this paper, the bit line voltage was set to approximately 2.0 V. In addition, V_{RA} tracks must track the sense amplifier pull-up to tolerate various processing and operating conditions.

SENSE AMPLIFIER AND REFERENCE GENERATOR

Current sensing was chosen over voltage sensing for three reasons. First, the input of the amplifier is a low impedance node, thus, bit-line charging is improved. The bit-line charging task is then shared by both the pull-up device and the sense amplifier. Second, the input node to a current sense amplifier typically sits at a lower voltage than a voltage sensing scheme using a differential pair; thus, the bit line need not charge as high. Third, the bit-line voltage need not change in current sensing; thus, the bit-line capacitance is not as dominant in determining the access time.

There are two disadvantages to current sensing in the ROM. First, if the resistance path from the cell to the sense amp is large, the cell will not experience the low-impedance characteristics of the sense amp, and thus the advantages of current sensing diminish. Second, the resistance data path from the cell to the sense amp must be balanced with the reference circuitry since this will determine the sensing current. Any misbalance, even in the dc condition, will degrade performance. Current flows through the pass transistors in the dc state in current sensing as opposed to voltage sensing where current drain to the sense amp is ideally zero in the steady state. Therefore, special care must be taken in the layout to assure symmetry with the reference and memory cell path.

The scheme chosen was a configuration similar to that reported by Wong *et al.* [3]. It is presently used on several commercially available products [4]. Independent references were used for each output to improve signal margins during transients. This technique minimizes ac and dc interaction between the different outputs, resulting in improved speed performance, even though it consumes more silicon area.

BACK BIAS GENERATOR

To meet the stringent standby power requirements of the chip, the back bias generator is designed to the following three specifications. First, it has a current drain of no more than 1 mA. Second, it performs throughout the temperature range with good stability. Third, it is supply independent to the first order.

A block diagram of the generator is shown in Fig. 6. It consists of a ring oscillator, buffer, capacitive pump, and a regulator. The ring oscillator is a

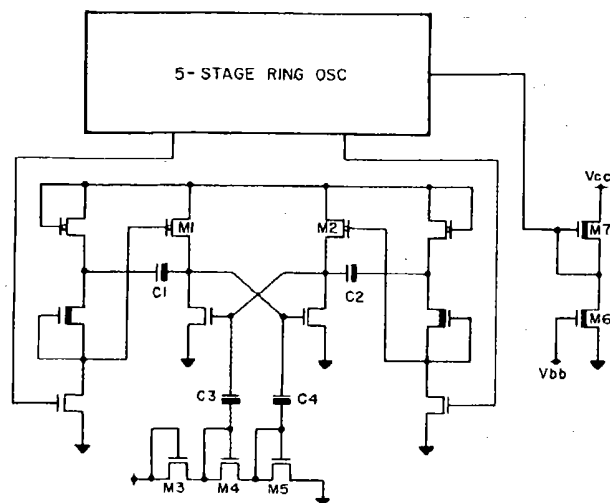


Fig. 6. Schematic of the back bias generator

five-stage inverter ring. The pull-ups in the oscillator were chosen as soft depletion transistors. This configuration draws much less operating current than depletion loads for a given silicon area. In addition, the pull-up devices stay in the active region longer, resembling that of an ideal load.

Soft enhancement devices used in the buffer stage are driven in a push-pull configuration to conserve power. Charging the two pump capacitors requires large pull-up devices which draw unacceptable power if loads were depletion devices. The tradeoff of using soft enhancement devices is that the output of the buffer will not swing to the full power supply range. To circumvent this problem, bootstrapping was used (C1 and C2) with small depletion pull-ups as the drivers to boost the gates of M1 and M2 to about +8.0 V.

The actual pumping is performed with C3 and C4 in conjunction with M3, M4, and M5 in a diode-connected configuration for clamping. A two-stage pump was chosen to pump to a maximum of $-7.0\ \text{V}$. To stabilize the substrate voltage, an inverter (M6 and M7), with the gate of the driver connected to the substrate, is used to disable the ring oscillator when V_{bb} is less than V_{TD} . This configuration is stable throughout supply voltage variations, temperature, and load conditions up to $40\ \mu\text{A}$.

EXPERIMENTAL RESULTS

The 256K ROM has a typical access time of 120 ns as shown in Fig. 2(b) and a typical chip select time of 120 ns. Active current is typically 60 mA with a standby current of 1.0 mA. The die size is 39K mil^2 .

ACKNOWLEDGMENT

The authors wish to thank J. Willis for layout, W. Park and R. Randolph for testing, the MTD Group of the Signetics Corporation for process support, and D. Puar, A. Frederick, and D. Lewis for encouragement.

REFERENCES

- [1] Y. Ystano *et al.*, "A 4Mb full wafer ROM," in *ISSCC Dig. Tech. Papers*, Feb. 1980, pp. 150-151.
- [2] P. A. Scherperg and D. Sheppard, "Asynchronous circuits accelerate access to 256K ROM," *Electronics*, pp. 141-145, June 1982.
- [3] J. Wong, M. Ebel, and P. Siu, "A 45 ns fully static 16K MOS ROM," *IEEE J. Solid-State Circuits*, vol. SC-16, pp. 592-594, Oct. 1981.
- [4] SY3316-High Speed 16K ROM, Synertek Inc., Santa Clara, CA 95057.